Web-Based 3D Reconstruction of Scenarios for Limited Objective Experiments

Curtis Blais, Don Brutzman, James Harney, Jeffrey Weekley
Naval Postgraduate School
777 Dyer Road Rm110D
Monterey, CA 93940
clblais@nps.navy.mil; brutzman@nps.navy.mil
jwharney@nps.navy.mil; jdweekle@nps.navy.mil

Keywords: Web3D, visual simulation, scenario reconstruction, Limited Objective Experiment

Abstract

The military is planning and conducting a large number of Limited Objective Experiments (LOEs) to explore new doctrine, organization, tactics, and technology with the objective of more rapidly transforming today's forces to better address the threat environment of the 21st Century. Web-based 3D technology is being investigated as a tool for creating reconstructions of LOE scenarios, enabling analysts to visualize and evaluate the actions that occurred or, if applicable, should have occurred. Moreover, creation of these virtual environments allows the analyst to consider alternative events, and to view them as if they had occurred (alternative realities). These alternatives can form the basis for deeper analysis of the scenario employed in the experiment or for planning follow-on experiments, to be conducted in the real world or in the virtual world. Indeed, the virtual world itself becomes an experimentation environment that can be manipulated by the analyst or explored through simulation techniques, such as agent-based simulation, to examine the space of potential outcomes.

This paper describes work performed by the Naval Postgraduate School in support of a Force Protection LOE and a Joint Futures Laboratory Peer-to-Peer Communications LOE using web-based 3D graphics, with preliminary agent-based simulation to explore the range of potential scenario outcomes.

BACKGROUND

The Naval Postgraduate School (NPS), with initial funding from the Defense Modeling and Simulation Office, began the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) project in mid-2000 [Blais et al. 2001]. The purpose of the SAVAGE project is to create authoring tools and techniques to generate interactive, multi-user, web-based 3D models of military operations. Foundational work at NPS and early work in the SAVAGE project focused on representation of 3D models and behaviors for visualizing communications plans [Laflam 2000; Hunsberger 2001], humanoid teams [Miller 2000], air tasking orders [Murray and Quigley 2000], and amphibious operations orders [Nicklaus 2001]. Recent work has extended these activities into reconstruction of actual events, including: the USS Greeneville/Ehime Maru collision off the coast of Oahu, Hawaii; the USS COLE terrorist attack in Aden Harbor, Yemen; and Autonomous Underwater Vehicle (AUV) mine-hunting test tracks [Weekley 2002].

Most recently, the project has supported web-based 3D visualization for two Limited Objective Experiments (LOEs), a Peer-to-Peer Communications experiment conducted at the Naval Postgraduate School for the Joint Futures Laboratory [Pilnick et al. 2002] and a Force Protection (FP) experiment to be conducted at Port Hueneme, California, in late summer 2002. This paper describes the technical approach and results (to date) for the LOEs, building on experience gained from the earlier work.

WEB3D AUTHORING AND VISUALIZATION

Web-based 3D (Web3D) refers to three-dimensional graphical models that can be exchanged and visualized through ordinary Web browsers (e.g., Netscape Navigator, Microsoft Internet Explorer). The Virtual Reality Modeling Language (VRML) is an established Internet standard [VRML 1997] for describing a scene graph – the virtual world consisting of geometric shapes and dynamic behaviors – that a user can interact with through his browser using freely available 3D plug-ins (e.g., Blaxxun Contact, Parallelgraphics Cortona, Nexternet Pivoron).

NPS is heavily engaged in specification of the next-generation Web3D standard, denoted X3D (Extensible 3D). X3D provides an encoding of the VRML standard in Extensible Markup Language (XML). The modeling described in this paper was performed using early X3D exemplar implementations.

Implementation of these models in a data exchange format that is readily transmitted over the Internet is key to widespread deployment of the models for web-based collaborative environments supporting planning, experimentation, analysis, and education. The models provide not just a visualization of the scenarios, but dynamic virtual environments within which the user can navigate freely for different perspectives of the scenarios in time and space. Complex behaviors can be embedded into the objects and actors within the scenes to create great variability in usage, from replay of preplanned or recorded motion and actions, to agent-based decision-making exhibiting possible behaviors, to multi-user human control of scenario objects and actors. This variability provides a rich environment for LOE planning and assessment.

The Web3D environments were constructed for the LOEs with the goal of providing insight into the LOE scenario events, both for pre-experiment planning of proposed events and for post-experiment reconstruction of actual events that occurred during the experiment. The analyst is able to pause, fast-forward, rewind, zoom in and out, and otherwise navigate through the scene to gain full spatial and temporal appreciation for the events of interest. Ultimately, it is hoped that these techniques will enhance planning and conduct of LOEs to more rapidly bring advantageous doctrines, tactics, procedures, weapons, information systems, and other LOE subjects of study to the warfighter.

U.S. ANTI-TERRORISM/FORCE PROTECTION

U.S. Naval forces have increasingly been at greater risk while deployed to foreign ports and harbors over the past decade. To continue to carry out the National Military Strategy of *engagement* with foreign countries through the navy, increased focus has been placed on the application of non-traditional non-lethal weapons along with new doctrinal development in order to ensure the security of our forces. The SAVAGE research group has taken a two-pronged approach in this arena: (1) conduct research and development in a Web context utilizing agent technologies to assist the analysis of LOE execution for the testing and evaluation of new weapons types; (2) provide a prototype tool for training and planning against the surface threat that can be expanded and utilized by fleet units.

A near term application for this emerging tool is an upcoming Force Protection LOE. LOE planners requested development of a visualization of the planned area of operations and primary scenario events for pre-experiment planning and post-experiment reconstruction. Creation of a fixed set of scenario events, or even reconstruction of actual events, cannot fully address "what-if" questions of interest in an FP scenario. For this reason, agent-based technologies have been incorporated within the research to allow a wide-spectrum of potential outcomes to be investigated, enabling the analyst to gain further insights towards solutions or vulnerabilities for the problem under analysis. In effect, the Web3D virtual environment becomes a laboratory for deeper investigation of both the planned and actual scenario events, as well as the "could have happened" events.

Creating the Building Blocks

Before undertaking extensive work towards creating both static and dynamic scenario examinations with regard to the FP LOE, initial tools and techniques had to be developed in order to streamline the reconstruction process. The following paragraphs describe work performed in the context of the Al-Qaida sponsored terrorist attack on the USS COLE (DDG 67) in Aden, Yemen in October 2000. These steps illustrate the foundation for the FP LOE work, presenting models and modeling techniques that were reused for the FP LOE.

Over 1200 pages from the U.S. Navy Court of Inquiry was available in the unclassified arena to conduct the reconstruction (http://www.foia.navy.mil/). After examination of these materials, it was determined that an appropriately detailed reconstruction would have to consist of the following:

- Creation of the land and sea space encompassing the area the major events occurred.
- Creation of the pier and other structures to which the COLE was moored.
- Creation of the various ships and small craft that played a role in the events that day.
- A visual representation of physical explosive effects to maintain scientific validity as closely as possible.
- Animation of all entities within the scene as portrayed in the Court of Inquiry.
- A means of allowing the user to control the animation (stop, play, rewind, etc.) as he views the simulation. Additionally, since the events modeled encompassed over three and one-half hours of scenario time, the user would require a means of fast-forwarding to points of interest or to reset the play-back to an earlier time as desired.

These considerations are typically important for other tactical scenarios as well, whether or not one is working in an LOE context.

Creation of Land and Sea Space

For the reconstruction of the Land and Sea Space for the attack on the COLE, it was determined that Digital Terrain Elevation Data (DTED) Level 1, which consists of terrain elevation postings at approximately 100 meter intervals, would be sufficient for our modeling purposes due to the mountainous terrain surrounding Aden Harbor and the location of the refueling dolphin in the harbor.

In our case, we chose to create sufficient land and sea space to reconstruct events from the beginning of the COLE transit into the port for refueling. The terrain data was read from DTED CD-ROM by a MatLab script, which wrote out the data as an X3D formatted file (XML encoding of VRML). The X3D file was then translated via an XML stylesheet into VRML syntax for viewing and manipulation in a standard web browser.

Creating the Refueling Dolphin

Creating refueling dolphin 7 that the USS COLE was moored to during the refueling operations that were on-going when the attack occurred proved to be fairly straightforward with the use of the Web3D provided open source tool for scene graph and geometry creation, X3D-Edit. X3D-Edit is a graphics file editor for Extensible 3D (X3D) that enables simple error-free editing, authoring, and validation of X3D scene graph files. Through the use of this editor, a fairly realistic depiction of the refueling pier was created (see Figure 2).

Creation of Ships and Small Craft

Due to the existence of the freely available SAVAGE online model library (see http://web.nps.navy.mil/~brutzman/Savage), many unclassified military models of interest exist that allow one to focus on the modeling and simulation of entity relationships as compared to focusing all efforts towards geometry creation. Figure 3 is a depiction of the Arleigh Burke class Destroyer model utilized in the reconstruction of the COLE attack. Various other models from the Savage library were utilized in addition to the creation of various low-resolution small boat entities that played a role in the scenario. It is important to note, however, that while "photo-realism" can be achieved with visual model content, it has been generally desirable to create models that correctly represent the geometry of a craft so that it can be recognized and then utilized in physical based simulation rather than investing undue time and effort in creating extremely high visual realism. In general, that level of visual realism is not needed for the planning and analysis efforts targeted for this work. More important is the accuracy of the event timelines and object behaviors.

Most models in the SAVAGE library were created by NPS students in an entry level or advanced X3D graphics programming course and are based on data from open sources such as the Federation of American Scientist's website (http://www.fas.org).

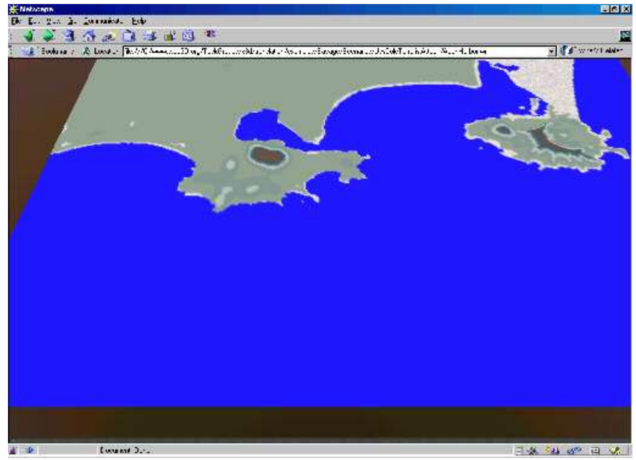

Figure 1. VRML97 rendering of the X3D representation of Aden Harbor, Yemen.

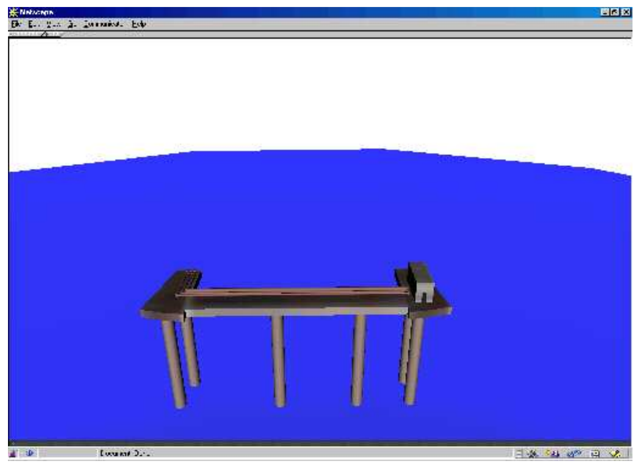

Figure 2. VRML97 rendering of the X3D representation for Refueling Dolphin 7 located at Aden Harbor, Yemen.

Representing Explosions

To model explosions, we used the U.S. Army's unclassified TNT equivalency model to represent the various ranges of damage that occur. An unclassified failure rate of steel was utilized to determine three levels of damage (structural failure, severe damage, and light damage). Each range was then represented through the use of different colored spheres that would allow the analyst to have a visual indication of the effectiveness of an attack while viewing the simulation. Although a more realistic appearing explosion might look better, it would give less insight to an observer of the simulation as to what the real effects of an explosion might be, or in the case of the COLE, what the actual effects were. By designing the explosion model as an X3D prototype, it is now available in the SAVAGE library for reuse or extension in LOEs or other projects.

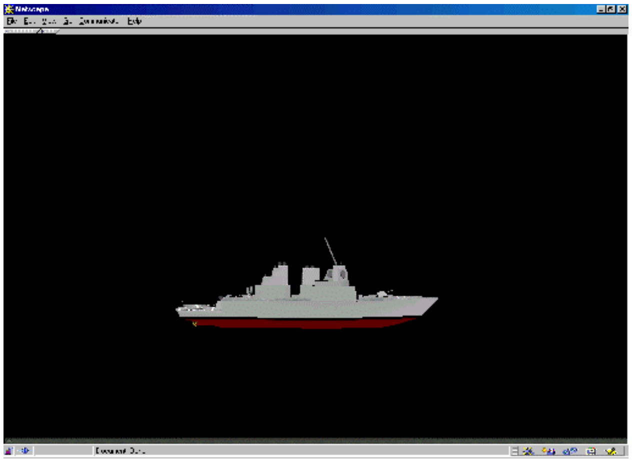

Figure 3. VRML97 rendering of the X3D representation of an Arleigh Burke Class Destroyer model from the SAVAGE model library.

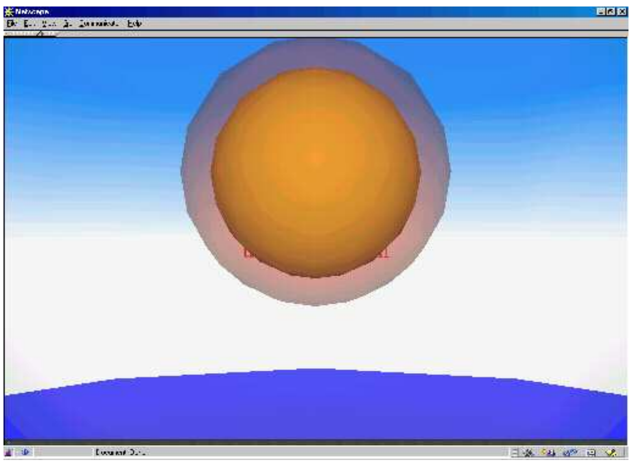

Figure 4. Physically-based explosion prototype from the SAVAGE model library.

Animation of Entity Tracks in a Reconstruction

Realistic animation of entities in scenario reconstruction can prove to be a difficult task when one considers the various factors that have to be taken into account in a 3D simulation representation (e.g., 6 degrees of freedom and physically-based modeling for all entities that are being portrayed). Smooth yet accurate animation of entities transitioning through a course change can prove to be mathematically tedious when the number of craft increases. As a simplification for rapid development of scenarios, the SAVAGE project team previously developed a Waypoint Interpolator prototype. This was employed to create the known track of the COLE and for the possible tracks of the terrorist boat and other craft (i.e., fixed tracks for planning or reconstruction, separate from introduction of agent or human control of entity movements). The mathematics required for entity animation and transition between waypoints were encapsulated in a reusable manner in the WaypointInterpolator PROTO node definition allowing a scene author to only worry about filling in the positions, speeds, and times for each course for an entity to maneuver. The capability for labeling waypoints, entity course, and entity depth or altitude provides another tool for the analyst to keep track of the relationship between time and position within the context of the model being portrayed.

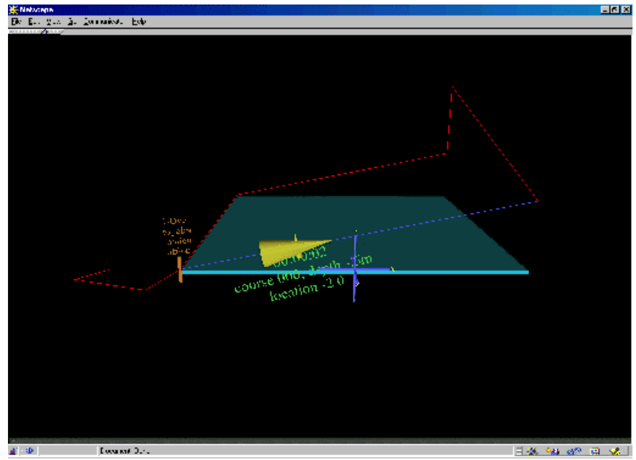

Figure 5. Waypoint Interpolator example.

Dynamic Scene Playback

Perhaps one of the most useful components developed within the SAVAGE project during the reconstruction of the attack on the COLE was the Digital Virtual Display (DVD) Prototype. Before its development, testing the reconstruction of scenes was extremely tedious when the developer had to wait a prolonged time period to observe critical events. Using the DVD controller, a user has multiple options by which to view a scene.

The user can play, pause, fast forward, rewind, or even dynamically move the scenario forward or backward in time using a slider located on the bottom of the controls. This prototype was used within the COLE scene graph to drive multiple waypoint interpolators that control the timing and movement of all craft and entities within the simulation. This mechanism allows multiple repetitions of key points in the critical events to be observed for many viewpoints and levels of fidelity. This is one of the advantages of reconstructing events with an interactive 3D tool – the user can analyze events from a spatial or temporal perspective in various ways that might provide new or quicker insights.

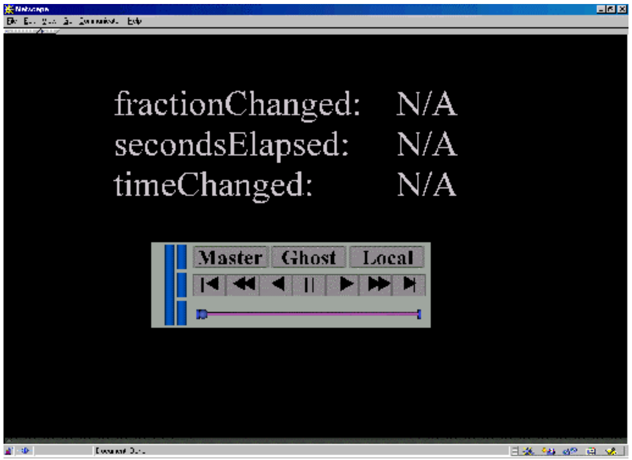

Figure 6. DVD prototype example.

Application to a Force Protection LOE

Static reconstruction of experiments allows us to examine events as they happen, but the capability to truly leverage current visualization technologies in this arena lies within the ability to dynamically simulate events and play “what if” scenarios. Coupled with the use of agent technologies, the analyst can now explore a much greater range of questions and possibilities before expending vital funds and other resources in an actual experiment.

For the upcoming FP LOE, a 2D planning tool (see Figures 7 and 8) was also developed to facilitate craft positioning and movement planning. A Web3D visualization of the scenario is then generated automatically from the planning tool input. To examine the planned scenario, a multi-layered intelligent agent approach is used (Figures 9 and 10). The initial layer can be considered as a “hands-off” approach wherein the planner defines the setup for the experiment, initiates the run, and views the computer-driven offensive and defensive agents playing out the simulation. The analyst can choose to run multiple scenarios with the same starting parameters without the visual display in order to more rapidly gather statistical data on the planned conditions. From this, the analyst can gain insight to various tactical parameters such as optimal picket boat placement against a surface threat, range parameters for identification and possible engagement of small craft, and redundancies required for effective defense, and then decide how to best arrange the naval forces taking part in the LOE in order to test the targeted equipment or doctrine without losing valuable experiment time.

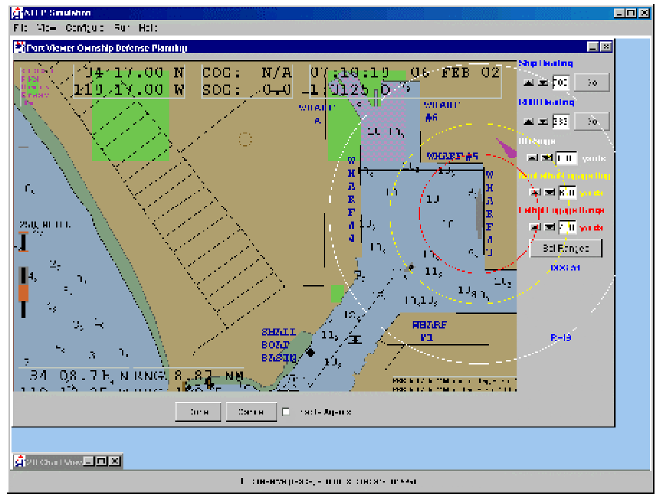

Figure 7. Depiction of simulation 2D setup for a LOE to be conducted in Port Hueneme, California.

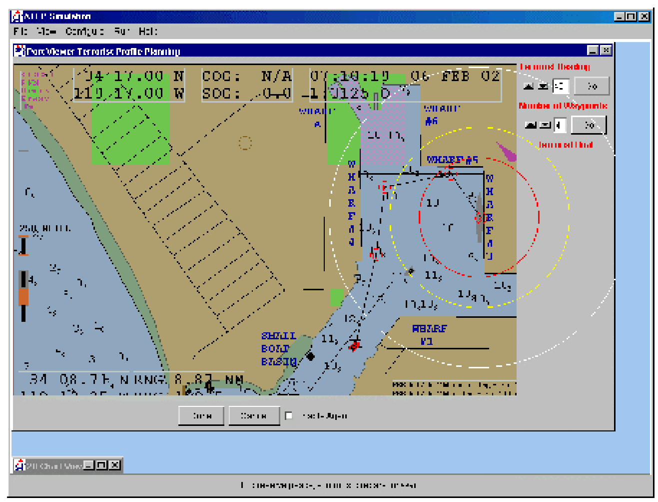

Figure 8. Depiction of simulation threat profile definition by the end-user.

Alternatively, a “human-in-the-loop” layer is also incorporated to allow the planner to play the role of the defense against the computer-driven offense, or to play the offense against the computer-driven defenses. In the Web-based environment, it is even possible to have multiple human analysts control various craft in the scenario, permitting analyst-versus-analyst interactions for examination of the scenario possibilities.

Through these various layers of control, an analyst can more thoroughly examine alternative experiment set-ups and then demonstrate the planned approach to other planners/sponsors.

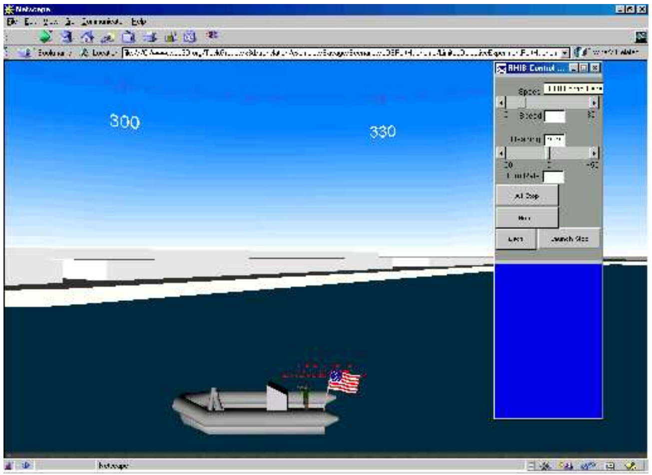

Figure 9. Graphical representation of defending RHIB in user control mode. Depicted is a conceptual representation of a non-lethal net entanglement system on the forward end of the RHIB.

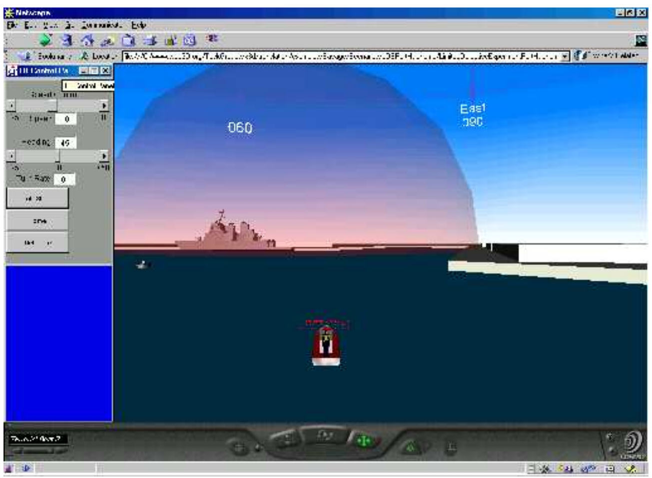

Figure 10. Graphical representation of attacking surface craft in agent control mode. Red (shaded) sphere depicted in background represents the High Value Unit's (DDG) lethal engagement range.

Additionally, new weapons and their employment can be simulated with enough fidelity to aid in the overall study. In this case, a specific non-lethal weapon under consideration for employment in the FP LOE was simulated in order to gain insight to potential employment possibilities and drawbacks.

Scaleable, dynamic, multi-user simulation for this research is achieved through the integration of the Distributed Interactive Simulation (DIS) standard protocol [IEEE 1995], JAVA software, and the VRML graphics format (obtained from translation of X3D files) [Brutzman 1998]. The DIS protocol is used to communicate state information (such as position, orientation, velocities, and accelerations) among multiple entities either participating on a shared network or on a single computer. Java is a portable networked programming language capable of interoperating on any computer that includes a web browser. In this case the DIS-JAVA-VRML integration is used as the means to control and render the simulation based on user or agent control inputs.

PEER-TO-PEER COMMUNICATIONS LOE

In support of the Peer-to-Peer (P2P) LOE sponsored by the Joint Futures Laboratory, NPS created a web-based 3D visual reconstruction of the scenario. The objective was to create a 3D model of the portion of the NPS campus where the experiment was conducted, together with graphical representations of the movement of student teams and their sightings as the scenario played out. The resulting dynamic playback scenes would be available in a form that could be readily shared across the network and viewed in standard browsers (Internet Explorer, Netscape Navigator) using freely available 3D plug-ins.

The setting for the P2P LOE was the NPS central Quadrangle, and consisted of several teams tasked with forward observation of an artificial hostage rescue scenario. It was not the intent of the scenario designers to replicate accurately the tactics and events of an actual hostage rescue operation. Instead, the purpose was to give the LOE some context or back-story, making events and motivations more understandable and stimulating to the participants.

The goals of the experiment included creating a sense of shared situational awareness among the peer teams and a reach-back facility by using technologies other than reliance on voice communications alone. Reconnaissance and Surveillance Teams (RSTs) used chat, map views and the Internet to achieve this objective. In the LOE, web-based 3D visualization was used to recreate the scenario as it played out and was not used in situ or during planning. We believe there is great promise in using 3D visualizations to augment the other means of establishing situational awareness during an operation, as well as for scenario planning and reconstruction of scenario events for review and analysis.

Web-Based 3D Technology

Key tools used in the P2P LOE reconstruction effort included:

- X3D-Edit, a scene graph editing tool configured for X3D using the IBM Xeena XML editor (http://www.alphaworks.ibm.com/tech/xeena), for authoring the 3D models and aggregate worlds.
- A Java-based translator program from the National Institutes of Standards and Technology (NIST) to convert native VRML97 models into X3D.
- A custom, Java-based tool to convert the data generated by the participants into 3D tracks which animate object

entities in the 3D world.

The Java program for converting track data to 3D visualization was an adaptation of track visualization software developed at NPS and recently employed in AUV mine warfare experiments [Weekley 2002].

Collecting the 3D Models

Several years ago, a previous NPS project built 3D graphical models of each building on the NPS campus using OpenInventor. OpenInventor is a powerful, proprietary software package that requires specialized software to view the 3D models. Like many other proprietary 3D authoring tools, OpenInventor allows the author to export models to the VRML standard format. VRML has become an important interchange format because it can be easily imported and exported by many proprietary authoring tools. The models were then converted to X3D using the tool provided by NIST. In X3D format, the products could be readily integrated into more complex scenes.

Building the 3D Quadrangle

To construct the 3D model of the area of the campus that would be used in the P2P LOE, a physical survey of the Quadrangle was performed. This survey identified distinctive trees, shrubs, succulents and other small plants, fire alarms, pedestrian barricades, bicycles, bike rack, WWII-era contact mine display, fire hydrant, benches, picnic tables, “Thai Hut” food vendor trailer, phone booth, clock, satellite dish, as well as the buildings around the area. In the final reconstruction, models of the following objects were used (see Figure 11): Root Hall, Spanagel Hall, Bullard Hall, Halligan Hall, Ingersoll Hall, Hermann Hall, Mechanical Engineering Building, Sidewalks and Roads, Satellite Dish, Street Lamp, Green Bench, Contact Mine, Thai Hut food stand and Parasol, Picnic Table, Free Standing Fire Alarm, Fire Hydrant, Phone Booth, Wooden Bench, and a Low Wooden Bench.

Of the models converted from the original formats, the Bullard Hall model was the only model that needed to be further modified, since the building had been repainted since the earlier models had been prepared. Adobe Photoshop was used to edit the original image used as a texture map on the building geometry. The new paint color was sampled from a digital photograph, and used to replace the old color on the original image. Generating imagery that can be used for precise texturing of 3D models is very complex, and it was easier to modify the image that already fit the model, as opposed to making a new image. The blue color of the old image was replaced with the orange color of the new paint scheme, and the image was then used as a texture on the building model, updating the paint scheme (see Figure 12).

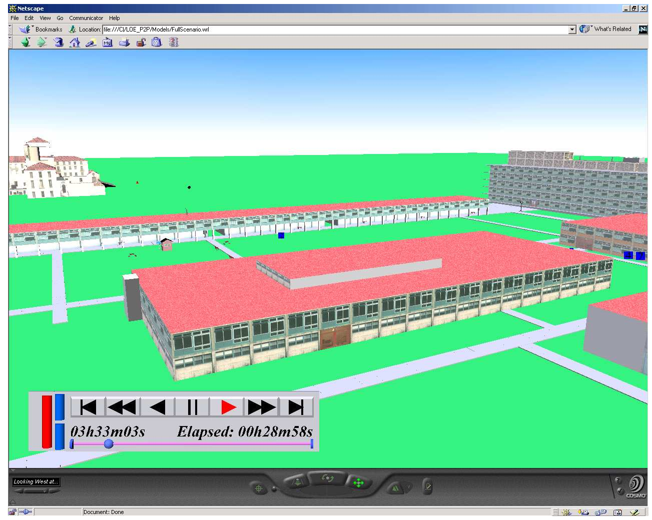

Figure 11. Virtual NPS Quadrangle and scenario playback control.

Figure 12. Old paint (blue, top) and modified image for new paint (orange, bottom) on Bullard Hall.

Because the 3D visualization needed to show the operation from perspectives not otherwise available, it was determined that the 3D campus should be built free of vegetation. This “tree-free” environment is still easily recognizable and allows for unobstructed observation from various vantage points in the scene. Foliage and natural forms can be difficult to author and represent. The high polygon count of a single, realistic looking tree could reduce graphics rendering performance to the point of annoyance. While simplistic models could be created, it is questionable whether they would add significant value to the scene if they were not sufficiently detailed to give good indication of clear and obstructed lines of sight. Moreover, it was decided that tree and foliage models would not display well on handheld devices such as those used by the RST members in this LOE. An area of future work would be to create a visualization allowing the user to selectively display or not display trees and foliage in the scene, possibly in user-specified regions of the scene or for particular lines of vision.

Visualizing Wireless Local Area Network (LAN) Coverage

A major aspect of the Peer-to-Peer communication infrastructure was the wireless LAN installed across the Quadrangle for the experiment. This was a combination of six wireless hubs and antennas. The coverage was purposefully spotty in order to investigate network traffic effects as teams entered and left coverage areas. To survey the experiment area, the Quadrangle was divided into 50 square meter sections, and signal strength was measured in each section. A graphical depiction of the signal strength in the area of coverage was created from the survey data. The resulting visualization served as the basis for a decision to place an additional wireless hub to provide somewhat better coverage of the region. Measurements were taken again, and the resulting signal visualization is shown in Figure 13.

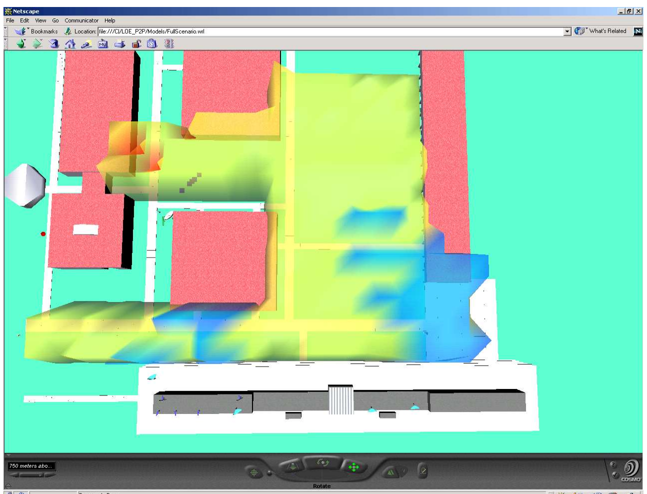

Figure 13. Wireless LAN signal strength visualization (from above).

The signal strength is indicated both by color and by height of the coverage region (i.e., poor signal strength is visualized in red at 10-meter height; moderate strength is visualized in yellow at 30-meter height; good signal strength is visualized in blue at 50 meter height).

Translating P2P LOE Scenario Data into 3D

During the 3.5 hours of the LOE execution, the Operations Center recorded over 20 Megabytes of data on own-team positions, situation reports, and sightings into a Microsoft Access database. The 29 tables of data contained time-stamped information on team positions and sightings (terrorists and “bombs”).

For track reconstruction, a query was written to extract time, position, and sighting information by RST from the tables. The data were then loaded into a Java program that parsed the data, and wrote out X3D-formatted track files for each object.

The resulting 3D visualization (for example, Figure 14) provides representations of the RSTs, terrorists and bombs, similar to the 2D representations used in LOE planning and scenario execution, but with the added dimension of time. Analysts could replay the experiment to see where each team was at any point in the experiment and what information each team held at that time.

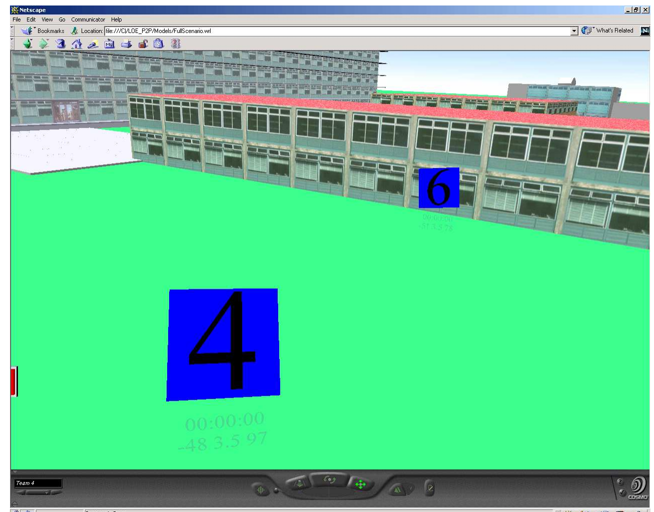

Figure 14. Team 4 and 6 icons positioned within the localized coordinate system.

Lessons Learned and Recommendations for Future Work

If the status of an object is reported accurately in near real time, it can be represented accurately in a distributed, multi-user 3D world, using the DIS-Java-VRML methodology for networked, interactive 3D simulations. The challenge is obtaining accurate reporting of the status of a real object, and then registering that location appropriately in the local coordinate system of the 3D scene graph.

Late in the planning phase of the LOE, it was discovered that the commercial Global Positioning System (GPS) was not providing accurate enough data to pinpoint locations of participants or observed objects. It was therefore decided that positions would be self-reported. It is obvious from the 3D scenario replay that the reported positions are not accurate or are lacking registration information. Most of the terrorist and bomb positions are well away from where the scenario actually occurred. More work is needed to fully determine the source of these errors. It is suspected that differential Global Positioning or military-grade GPS would have yielded better results or that necessary position registration data that may have been available to the shared applications was not stored in the recorded data tables.

A key enabler in the reconstruction of the LOE scenario was re-use of existing 3D models through the NIST translation tool. As stated earlier, the international VRML standard continues to be a valuable 3D scene interchange format for multiple applications, including support for web-based 3D visualizations. In addition, development of software to convert from the raw data files into text-based X3D file formats was straightforward. Such automated techniques demonstrate the power and simplicity of the XML standard for Web-based data interchange.

This work further demonstrated that the generation of meaningful 3D worlds for Web-based distribution is becoming practical for a wide range of applications. There is significant potential for using the 3D visualizations in LOE planning, allowing the planners to "walk through" the timeline and major scenario events within the 3D world. Moreover, 3D visualization of the scenario area would have enriched the team and participant training sessions, particularly for those participants not familiar with the NPS campus. Given a reliable data stream of position information and sightings during conduct of the scenario, it is feasible for the 3D visualization to be updated near-real time, so as to augment the 2D situation displays that were provided in the Operations Center and on RST devices.

Visualization of the signal strength across the physical LOE area (Figures 13) demonstrated the potential to visualize aspects of a problem not normally visible to planners and participants. It may be feasible to feed network reliability information from the monitoring software running in the Operations Center to update this visualization as well, so that actual dynamic performance of the wireless LAN could be displayed. Perhaps one day it will be possible to "seed" an area with a large number of small sensors that can provide real-time signal strength monitoring over the area of an operation such as this. Such reporting could then be passed to the visualization system.

The other quality of the Web3D visualization that was not exploited during the P2P LOE is its Web-based capability. As an XML representation of the scene graph, the X3D models developed for the P2P LOE reconstruction are simply text files that are readily exchanged over networks, and can be viewed in common Internet browsers (using freely available 3D plug-ins). The ability to dynamically update and route 3D visualizations of a scenario across a network, whether a local-area network or a wide-area network (e.g., for reach-back), would be a valuable area for a future LOE related to Common Relevant Operational Picture (CROP) concepts being studied by the Joint Futures Laboratory.

CONCLUSIONS

Web3D is a powerful medium for construction, dissemination, and employment of dynamic, interactive, multi-user virtual environments. Used for simplistic, rapid, low-cost visualization or integrated with sophisticated software for agent-based behaviors and physically-based models, Web3D is proving to be an effective tool for providing insights into real-world scenario planning and reconstruction. The technology is helping analysts more effectively assess tactics, techniques, procedures, weapons, and other systems that can benefit today's and future warfighters.

REFERENCES

Blais, C.L.; D. Brutzman; D.P. Horner; S. Nicklaus. 2001. "Web-Based 3D Technology for Education – the SAVAGE Project." In Proceedings, 2001 Interservice/Industry Training, Simulation, and Education Conference (Orlando, FL, Nov. 26-29).

Brutzman, D. 1998. "The Virtual Reality Modeling Language and Java." *Communications of the ACM.* 41:6, June, pp 57-64.

IEEE. 1995. *Standard for Distributed Interactive Simulation Application Protocols*. IEEE Std 1278.1-1995. Institute of Electrical and Electronic Engineers.

Hunsberger, M.G. 2001. "3D Visualization of Tactical Commuincations for Planning and Operations Using Virtual Reality Modeling Language (VRML) and Extensible 3D (X3D)." Master's Thesis, Naval Postgraduate School.

Laflam, D. 2000. "3D Visualization of Theater-Level Radio Communications Using a Networked Virtual Environment." Master's Thesis, Naval Postgraduate School.

Miller, T.E. 2000. "Integrating Realistic Human Group Behaviors into a Networked 3D Virtual Environment." Master's Thesis, Naval Postgraduate School.

Murray, M.W, and J.M. Quigley. 2000. "Automatically Generating a Distributed 3D Battlespace Using USMTF and XML-MTF Air Tasking Order, Extensible Markup Language (XML), and Virtual Reality Modeling Language (VRML)." Master's Thesis, Naval Postgraduate School.

Nicklaus, S. 2001. "Scenario Authoring and Visualization for Advanced Graphical Environments." Master's Thesis, Naval Postgraduate School.

Pilnick, S.E; K. Curtis; F.R. Richards; W. Kemple; A. Bordetsky; R. Buddenberg; S. Hutchins; J. Kline; R. Adamo; D. Boger. 2002. "Peer-to-Peer Limited Objective Experiment." Technical Report (to be published). Naval Postgraduate School, Monterey, California.

VRML. 1997. VRML 97 International Specification. ISO/IEC 14772-1:1997. (http://www.web3d.org/technicalinfo/specifications/vrml97/index.htm)

Weekley, J. 2002. “Technical Report for AUVFest 2001.” ROLANDS & ASSOCIATES Corporation, Monterey, California, January.

Author Biographies

Curtis Blais is a Research Associate in the NPS Modeling, Virtual Environments, and Simulation (MOVES) Institute at the Naval Postgraduate School. His principal research areas include Web-based 3D graphics for military education and training, Web-based instruction, C4I virtual training environments, and agent-based systems. Prior to coming to NPS, Mr. Blais spent 25 years in software development in industry and government working on Navy and Marine Corps command staff training systems and C4I simulations. He designed and developed combat models for several generations of Marine Corps systems, and continues to support design of the next-generation command staff training system, the Joint Simulation System (JSIMS). Mr. Blais has a B.S. and M.S. in Mathematics from the University of Notre Dame, and is working toward a PhD in MOVES at NPS.

Don Brutzman is Assistant Professor at NPS in the MOVES Institute and the Undersea Warfare Academic Group. Dr. Brutzman's research efforts include 3D real-time virtual worlds and 3D visualization of sonar signals and autonomous underwater vehicles (AUVs); machine learning, sensing, perception, and control; and distributed audio, video, and graphics applications using multicast, distributed interactive simulation, and adaptive protocols for large-scale virtual environments. Dr. Brutzman is leading efforts in the Web3D Consortium to develop next-generation Web3D specifications and tools, and is a member of the US Government XML Working Group. Dr. Brutzman served 20 years in the U.S. Navy as Electrical Officer, Combat Systems Officer, and Navigator aboard submarines, and was Operational Test Director for testing of the CCS MK 1 Combat Control System and Mk 48 Advanced Capability (ADCAP) torpedo. Dr. Brutzman obtained a B.S. in Electrical Engineering at the U.S. Naval Academy and a M.S. in Computer Science at NPS. Dr. Brutzman received a PhD in Computer Science, with a minor in Operations Research, from NPS in 1994.

James Harney, LT, United States Navy, is a student at NPS completing a M.S. in Computer Science. His thesis research involves the utilization of X3D Web-based graphics and agent technologies to gain insight into modeling and simulation of Anti-Terrorism and Force Protection measures for U.S. Navy warships. Prior to coming to NPS, LT Harney served as commissioning Damage Control Assistant on USS ROSS (DDG 71) followed by a tour as Combat Information Center Officer on USS PETERSON (DD 969). LT Harney earned a B.S. in Computer Science from the U.S. Naval Academy in 1996. Following graduation from NPS in March 2003, LT Harney will be assigned to Surface Warfare Officer’s School in Newport, Rhode Island for department head training.

Jeffrey Weekley is a Research Associate at NPS in the MOVES Institute. Before joining NPS, he worked at ROLANDS & ASSOCIATES Corporation in 3D content development, web graphics research and technical writing for simulation and modeling efforts. He is a former Navy Cryptolinguist. After leaving the Navy, he worked as an Operations Analyst in the biotech, semiconductor, aerospace and pharmaceutical industries. He has a degree in Communications from the University of Northern Iowa and two degrees in linguistics from the Defense Language Institute, Monterey, California.